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## **Adaptive Statistical Iterative Reconstruction-V: Impact on Image Quality in Ultralow-Dose Coronary Computed Tomography Angiography**

Benz, Dominik C ; Gräni, Christoph ; Mikulicic, Fran ; Vontobel, Jan ; Fuchs, Tobias A ; Possner, Mathias ; Clerc, Olivier F ; Stehli, Julia ; Gaemperli, Oliver ; Pazhenkottil, Aju P ; Buechel, Ronny R ; Kaufmann, Philipp A

**Abstract:** **OBJECTIVE** The clinical utility of a latest generation iterative reconstruction algorithm (adaptive statistical iterative reconstruction [ASiR-V]) has yet to be elucidated for coronary computed tomography angiography (CCTA). This study evaluates the impact of ASiR-V on signal, noise and image quality in CCTA. **METHODS** Sixty-five patients underwent clinically indicated CCTA on a 256-slice CT scanner using an ultralow-dose protocol. Data sets from each patient were reconstructed at 6 different levels of ASiR-V. Signal intensity was measured by placing a region of interest in the aortic root, LMA, and RCA. Similarly, noise was measured in the aortic root. Image quality was visually assessed by 2 readers. **RESULTS** Median radiation dose was 0.49 mSv. Image noise decreased with increasing levels of ASiR-V resulting in a significant increase in signal-to-noise ratio in the RCA and LMA ( $P < 0.001$ ). Correspondingly, image quality significantly increased with higher levels of ASiR-V ( $P < 0.001$ ). **CONCLUSIONS** ASiR-V yields substantial noise reduction and improved image quality enabling introduction of ultralow-dose CCTA.

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# Adaptive Statistical Iterative Reconstruction-V: Impact on Image Quality in Ultralow-Dose Coronary Computed Tomography Angiography

Dominik C. Benz, MD, Christoph Gräni, MD, Fran Mikulicic, MD, Jan Vontobel, MD, Tobias A. Fuchs, MD, Mathias Possner, MD, Olivier F. Clerc, MD, Julia Stehli, MD, Oliver Gaemperli, MD, Aju P. Pazhenkottil, MD, Ronny R. Buechel, MD, and Philipp A. Kaufmann, MD

**Objective:** The clinical utility of a latest generation iterative reconstruction algorithm (adaptive statistical iterative reconstruction [ASiR-V]) has yet to be elucidated for coronary computed tomography angiography (CCTA). This study evaluates the impact of ASiR-V on signal, noise and image quality in CCTA.

**Methods:** Sixty-five patients underwent clinically indicated CCTA on a 256-slice CT scanner using an ultralow-dose protocol. Data sets from each patient were reconstructed at 6 different levels of ASiR-V. Signal intensity was measured by placing a region of interest in the aortic root, LMA, and RCA. Similarly, noise was measured in the aortic root. Image quality was visually assessed by 2 readers.

**Results:** Median radiation dose was 0.49 mSv. Image noise decreased with increasing levels of ASiR-V resulting in a significant increase in signal-to-noise ratio in the RCA and LMA ( $P < 0.001$ ). Correspondingly, image quality significantly increased with higher levels of ASiR-V ( $P < 0.001$ ).

**Conclusions:** ASiR-V yields substantial noise reduction and improved image quality enabling introduction of ultralow-dose CCTA.

**Key Words:** adaptive statistical iterative reconstruction V, ultralow-dose CCTA, coronary computed tomography, noise reduction, dose reduction

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Coronary computed tomography angiography (CCTA) has become an important noninvasive tool for the evaluation of coronary artery disease (CAD). However, its growing clinical use has raised concerns about the increased burden of radiation exposure for patients.<sup>1</sup> Because cumulative radiation exposure should be “as low as reasonably achievable,” various strategies have been developed to enable low-dose CCTA. Most importantly, prospectively electrocardiogram triggered axial acquisition,<sup>2,3</sup> including high-pitch helical scanning,<sup>4</sup> has paved the way for a reduction of radiation dose exposure from over 20 mSv with conventional helical acquisition<sup>5</sup> to around 2 mSv in daily clinical routine.<sup>2</sup> However, despite these impressive technological advances in CT hardware, with traditional reconstruction methods, such as filtered back projection (FBP), increased image noise and degraded image quality have limited further dose reduction by means of tube current and voltage decrease. To overcome this impediment, several types of iterative reconstruction (IR) methods have been developed and validated for different clinical indications.<sup>6–10</sup>

From the Department of Nuclear Medicine, Cardiac Imaging, University Hospital Zurich, Ramistrasse, Zurich, Switzerland.

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Correspondence to: Ronny R. Buechel, MD, Department of Nuclear Medicine, Cardiac Imaging, University Hospital Zurich, Ramistrasse 100 CH-8091, Zurich, Switzerland (e-mail: ronny.buechel@usz.ch).

D.C.B. and C.G. share first authorship. R.R.B. and P.A.K. share last authorship.

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With adaptive statistical iterative reconstruction (ASiR; GE Healthcare, Waukesha, WI USA) preserved signal-to-noise ratio (SNR) and study interpretability was demonstrated despite a 44% radiation dose reduction.<sup>11</sup> On the downside, higher levels of ASiR have been reported to cause image quality issues, such as an increasing “plastic” appearance.<sup>12</sup>

A novel model-based IR algorithm (Veo; GE Healthcare) provides considerably better image quality than FBP and ASiR,<sup>6,13</sup> with high diagnostic accuracy even at ultralow radiation doses,<sup>14</sup> but has not yet been implemented in clinical routine for cardiac CT due to its high computational requirements and long processing time.

As an alternative, a modification of ASiR (ASiR-V; GE Healthcare) has been suggested with more advanced system noise statistics as well as object modeling and added physics modelling—the major contributors to noise reduction and low-contrast resolution improvements. These complex prediction models include modeling of exact geometric features of the cone beam and the absorbing voxels as well as x-ray physics (eg, scatter, crosstalk). Thereby, ASiR-V substantially reduces image noise and improves contrast-to-noise ratio (CNR) compared with FBP and ASiR as documented in a recent phantom study.<sup>15</sup> However, no data are available on the performance of ASiR-V for CCTA in a clinical setting with humans.<sup>10</sup>

The aim of the present study was to investigate the impact of ASiR-V on SNR, CNR, and image quality, and to determine the optimal combination of ASiR-V and FBP in patients referred for noninvasive evaluation of CAD by CCTA.

## MATERIALS AND METHODS

### Patient Population

We prospectively included 65 consecutive patients who were referred for the assessment of known or suspected CAD with CCTA. Exclusion criteria were known hypersensitivity to iodinated contrast agents and renal insufficiency (glomerular filtration rate,  $<60$  mL/min). The study was approved by the local ethics committee (KEK-ZH-Nr. 214–0632), and all patients provided written informed consent.

### Image Acquisition

All patients underwent contrast-enhanced CCTA during breath-hold at inspiration with prospectively electrocardiogram-triggered axial acquisition at 75% of the R-R interval with no padding used and with single-beat 16-cm coverage on a latest generation 256-slice high-resolution CT scanner (Revolution CT; GE Healthcare). Up to 30 mg metoprolol (Beloc Zok; Astra Zeneca, London, UK) was administered intravenously before the examination if heart rate was higher than 65 per minute to obtain optimal image quality for CCTA.<sup>3</sup> Patients received 0.4 mg

sublingual isosorbiddinitrate (Isoket; Schwarz Pharma, Monheim, Germany) 2 minutes before the CCTA scan.

Iodixanol (Visipaque 320, 320 mg/mL; GE Healthcare, Buckinghamshire, UK) was injected into an antecubital vein followed by 50-mL saline solution via an 18-gauge catheter. Contrast volume (25–45 mL) and flow rate (3.5–5 mL/s) were adapted to body mass index according to our clinical experience.<sup>16</sup> For CCTA acquisition, collimation of  $256 \times 0.625$  mm and gantry rotation time of 0.28 seconds was used, field of view was 25 cm. Tube voltage (80–120 kVp) and tube current (180–310 mA) were adapted to body mass index.<sup>6</sup> All scans were acquired in high-resolution mode with an in-plane spatial resolution of  $0.23 \times 0.23$  mm.

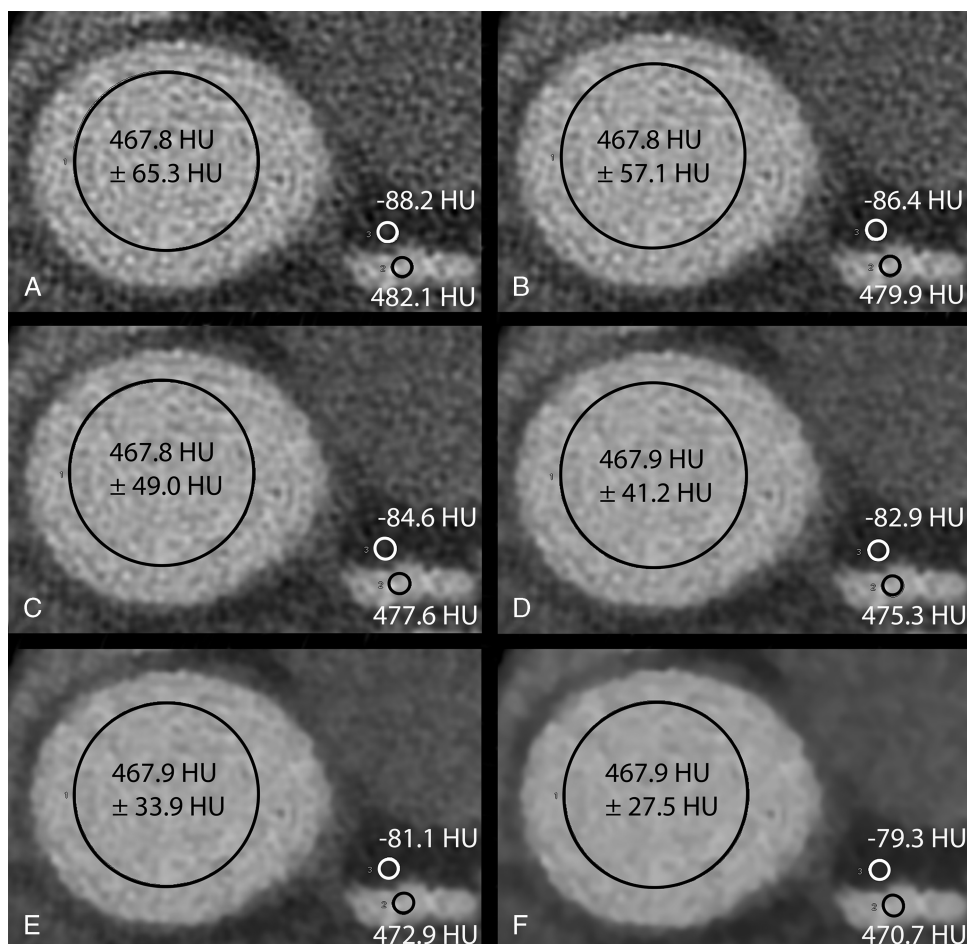
## Image Reconstruction

The image reconstruction process allows a combination of FBP with ASiR-V at incremental blending factors ranging from 0% to 100%. Thus, images with 0% ASiR-V represent a reconstruction with FBP only, whereas images with 1% to 99% ASiR-V consist of a composite of ASiR-V with the inverse proportion of FBP, and 100% ASiR-V resembles a reconstruction with ASiR-V only. Six data sets with increasing blending factors (ie, 0%, 20%, 40%, 60%, 80%, and 100% ASiR-V) were reconstructed for each patient using a high-definition kernel with a

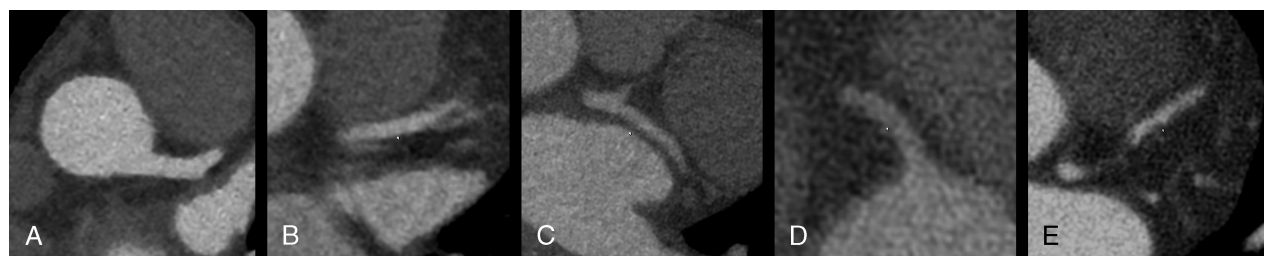
display field of view of 25 cm. Radiation dose for CCTA was determined by the dose-length product multiplied by the conversion factor of  $0.014 \text{ mSv} \times \text{mGy}^{-1} \times \text{cm}^{-1}$ .

## Quantitative Image Analysis

On a dedicated workstation (Advantage Workstation 4.6; GE Healthcare), for every patient, the aortic root was examined at the level of the left main coronary artery on an axial image using a region of interest (ROI) with 20 mm diameter to measure mean attenuation (representing signal) and its standard deviation (SD, representing noise) in Hounsfield units (HU). Similarly, measurements of mean attenuation in the proximal LMA and RCA were obtained using a ROI with 2-mm diameter on axial images and due care was taken to avoid calcifications and streak artefacts. Finally, a ROI with 2-mm diameter was placed in the adjacent perivascular tissue to measure the vessel contrast expressed as the difference in mean attenuation in HU between the contrast enhanced vessel and the adjacent perivascular tissue (Fig. 1). To ensure that the same location was measured in all reconstructions, a semiautomated tool was used (Compare Viewer; GE Healthcare). The obtained measurements were used to calculate CNR, for which noise was defined as the standard deviation in the aortic root ( $[\text{Mean attenuation}^{\text{LMA or RCA}} - \text{Mean attenuation}^{\text{perivascular tissue}}] / \text{Standard deviation}^{\text{Aortic root}}$ ). Correspondingly, the signal-to-noise



**FIGURE 1.** Axial images depicting the aortic root and the left main (LM) artery at different ASiR-V levels (A 0%, B 20%, C 40%, D 60%, E 80%, and F 100%). Attenuation was measured in HU in the aortic root, in the proximal LM and the adjacent perivascular fat. Similarly, attenuation was measured in the proximal right coronary artery and the adjacent perivascular fat (not shown).



**FIGURE 2.** The examples of each level of image quality give an impression on how the readers assessed the image quality, with Likert scales 5 (A), 4 (B), 3 (C), 2 (D) and 1 (E).

was calculated as the ratio between the mean attenuation in the coronary artery (LMA or RCA) and the standard deviation in the aortic root.

### Qualitative Image Analysis

Qualitative image assessment was performed visually by 2 independent readers experienced in CCTA analysis. Six reconstructions (ie, 0%, 20%, 40%, 60%, 80%, and 100% ASiR-V) were reconstructed for each patient and transferred to a dedicated workstation (AW 4.6; GE Healthcare). The reconstructed data sets were presented to each reader in a randomized order and without any annotations to ensure blinding of the readers to patient information and to the ASiR-V level used for reconstruction. Axial image stacks were reviewed, and an image quality score was assigned for each coronary artery segment,<sup>17</sup> based on a 5-point Likert scale as previously described:<sup>12</sup> 1, poor, impaired image quality limited by excessive noise or poor vessel wall definition; 2, adequate, reduced image quality with poor vessel wall definition or excessive image noise, limitations in low contrast resolution remain evident; 3, good, impact of image noise, limitations of low contrast resolution and vessel margin definition are minimal; 4, very good, good attenuation of vessel lumen and delineation of vessel walls, relative image noise is minimal, coronary wall definition, and low contrast resolution well maintained; and 5, excellent, excellent attenuation of the vessel lumen and clear delineation of the vessel walls, limited perceived image noise (Fig. 2).

Readers were instructed to ignore issues leading to degradation of image quality that could not be attributed to the reconstruction algorithm, such as motion artefacts. Importantly, all segments present were evaluated regardless of size. The mean value of the image quality scores from all coronary artery segments of 1 data set was used for statistical analysis.

### Statistical Analysis

Quantitative variables are expressed as mean  $\pm$ SD or as median with interquartile range (IQR) if not normally distributed. Categorical variables are expressed as frequencies or percentages. The data were tested for normal distribution using the Kolmogorov-Smirnov test. ASiR-V reconstructions were compared using repeated-measures analysis of variance, and post hoc pairwise comparisons were adjusted for multiple comparisons by the Bonferroni correction. Nonparametric variables were compared using the Friedman test. Inter-reader agreement was assessed for all patients and ASiR-V reconstructions using intraclass correlation analysis. For assessment of intrareader agreement, the first 20 consecutive patients were analyzed. To assess the correlation between quantitative and qualitative variables, Spearman correlation was applied. SPSS 20.0 (IBM Corporation, Armonk, NY) was used for analysis. A *P* value less than 0.05 was considered statistically significant.

## RESULTS

### Study Population

Sixty-five consecutive patients were included in the study. The patient baseline characteristics are summarized in Table 1. Median voltage was 100 kV (IQR, 100–100 kV), median current was 290 mA (IQR, 225–355 mA), resulting in a median effective radiation dose of 0.49 mSv (IQR, 0.4–0.6 mSv). The median contrast agent volume was 35 mL (IQR, 30–40 mL). Mean heart rate was  $58 \pm 8$  bpm, with 9% of patients having a heart rate above 65 bpm.

### Quantitative Image Analysis

An overview on the quantitative measurements is given in Table 2. Although signal intensity in the aortic root remained unchanged among the different levels of ASiR-V (*P* = ns), there was a slight but statistically significant decrease in signal intensity in the LMA and RCA with increasing ASiR-V levels (*P* < 0.001). By contrast, image noise decreased substantially with increasing ASiR-V levels, resulting in a significant increase of the SNR and CNR in the LMA and RCA.

Moreover, post hoc pairwise comparison with Bonferroni adjustment revealed greatest noise reduction and highest SNR as well as highest CNR in reconstructions with 100% ASiR-V (*P* < 0.001; Table 2). Compared with 100% ASiR-V, there was a relative increase of noise in the aortic root of +28%, +60%, +92%, +128%, and +164% for reconstructions using 80%, 60%, 40%, 20%, and 0% ASiR-V, respectively. Conversely, compared

**TABLE 1.** Patient Baseline Characteristics (n = 65)

Male sex (%)	59
Age, y	
Median	58
Interquartile range	45–63
Cardiovascular risk factors	
Body mass index, kg/m <sup>2</sup>	
Median	25.7
Interquartile range	22.2–28.9
Smoking (%)	31
Diabetes mellitus (%)	5
Hypertension (%)	45
Dyslipidemia (%)	37
Positive family history of (%)	25
Clinical symptoms (%)	
Typical angina pectoris	3
Atypical chest pain	39
Dyspnoea	15

**TABLE 2.** Quantitative and Qualitative Image Analysis

	Percentage ASiR-V Used for Image Reconstruction						
Variable	0%	20%	40%	60%	80%	100%	P
Quantitative image analysis							
Signal AR (HU)	412 ± 88	412 ± 88	412 ± 88	412 ± 88	411 ± 88	412 ± 88	n.s.
Signal LMA (HU)	396* ± 79	393* ± 79	390* ± 79	387* ± 79	384* ± 79	381 ± 79	<0.001
Signal RCA (HU)	370* ± 70	366* ± 70	363* ± 71	359* ± 71	356* ± 72	352 ± 73	<0.001
Noise aortic root (HU)	66* ± 10	57* ± 8	48* ± 7	40* ± 5	32* ± 4	25 ± 4	<0.001
SNR LMA	6.3* ± 1.8	7.1* ± 1.9	8.3* ± 2.0	9.8* ± 2.1	12.1* ± 2.1	15.3 ± 2.3	<0.001
SNR RCA	5.9* ± 1.8	6.7* ± 1.9	7.7* ± 2.0	9.2* ± 2.1	11.3* ± 2.2	14.2 ± 2.6	<0.001
CNR LMA	8.0* ± 2.3	9.1* ± 2.4	10.5* ± 2.5	12.4* ± 2.5	15.1* ± 2.5	19.0 ± 2.7	<0.001
CNR RCA	7.8* ± 2.5	8.8* ± 2.6	10.1* ± 2.7	12.0* ± 2.7	14.5* ± 2.9	18.4 ± 3.1	<0.001
Image quality score							
Reader 1	1.9* ± 0.4	2.0* ± 0.5	2.3* ± 0.5	2.7* ± 0.6	3.2* ± 0.7	3.6 ± 0.6	<0.001
Reader 2	1.6* ± 0.3	1.7* ± 0.3	2.0* ± 0.4	2.3* ± 0.5	2.8* ± 0.6	3.4 ± 0.4	<0.001

Mean values and standard deviations are given.

\*Post-hoc pairwise comparison with Bonferroni-adjustment for multiple comparison reveals significant mean differences from ASiR-V 100% ( $P < 0.001$ ).

LMA indicates left main artery; RCA, right coronary artery; n.s., not significant.

with 100% ASiR-V, a relative decrease of SNR in the LMA of -21%, -36%, -46%, -54%, and -59% was observed for reconstructions using 80%, 60%, 40%, 20%, and 0% ASiR-V, respectively. In the RCA, similar relative decrease of SNR was found: -20%, -35%, -46%, -53%, and -58%, for reconstructions using 80%, 60%, 40%, 20%, and 0% ASiR-V, respectively.

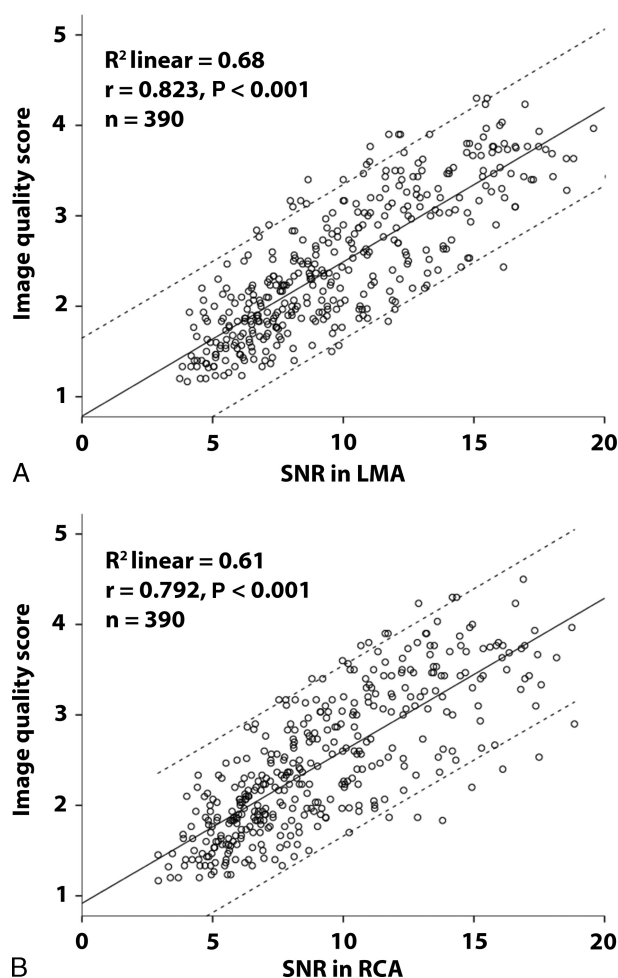
### Qualitative Image Analysis

Results of the qualitative image analysis are given in Table 2. Image quality, as assessed visually, significantly improved with increasing ASiR-V levels. Post hoc pairwise comparison with Bonferroni adjustment revealed the highest values (ie, 3.6 and 3.4 for readers 1 and 2, respectively) for reconstructions using 100% ASiR-V. Of note, for both readers, reconstructions with 100% ASiR-V were scored significantly better than reconstructions with 80% ASiR-V (for reader 1: mean difference = 0.4,  $P < 0.001$ ; for reader 2: mean difference = 0.6,  $P < 0.001$ ). Inter-reader ( $i = 0.88$ ,  $P < 0.001$ ) and intrareader ( $r = 0.91$ ,  $P < 0.001$ ) agreement was excellent. Consequently, the mean values between the 2 readers were calculated for each patient and each ASiR-V level to perform a correlation with quantitative image analysis. Image quality correlated strongly and significantly with SNR in the LMA and the RCA ( $P < 0.001$ ; Fig. 3).

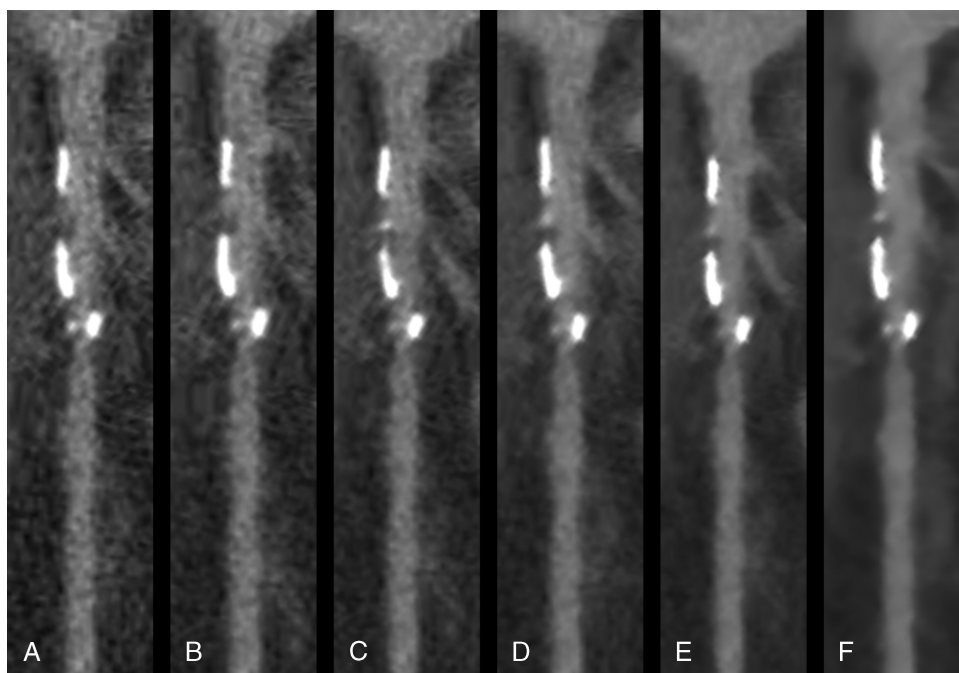
### DISCUSSION

In this study, increasing ASiR-V levels resulted in significant noise reduction, improved SNR and better image quality for CCTA data sets acquired at ultralow radiation exposure (median, 0.49 mSv). In comparison with 0% to 80% ASiR-V, reconstructions with 100% ASiR-V not only provided the largest noise reduction and highest SNR but also offered the best image quality. Of note, the increase in image quality correlated strongly with increasing SNR.

These findings suggest that the noise reduction capabilities of ASiR-V may allow implementation of lower tube voltage and current without amplifying image noise or compromising image quality. Compared with ASiR, the latest generation ASiR-V used in the present study results in enhanced noise reduction, confirming the findings of a prior phantom study<sup>15</sup> by extending it to



**FIGURE 3.** Correlation between image quality (i.e. mean values between both readers) and SNR for each patient and each ASiR-V level. Image quality correlated strongly and significantly with SNR in the LMA (A) and in the RCA (B).



**FIGURE 4.** Curved multiplanar reformations depict a high-grade stenosis in the mid-LAD at different ASiR-V levels (A 0%, B 20%, C 40%, D 60%, E 80%, and F 100%). An 80% stenosis of the mid-LAD was confirmed by invasive coronary angiography, and the patient was successfully revascularized with a drug-eluting stent.

clinical CCTA in humans. As a consequence, ASiR-V may complement the tools and strategies for radiation dose reduction. Furthermore, the results of the present study demonstrate that increasing levels of ASiR-V led to a continuous improvement of image quality. In fact, at least for ultralow-dose CCTA, reconstructions with 100% ASiR-V yield the best image quality (Fig. 4). This is in contrast with previous studies performed with the precursor of ASiR-V (ie, ASiR) for which degradation of image quality has been observed at levels of 80% and above, due to increasing artificial texture perceived as a “plastic” appearance.<sup>12,18</sup> Interestingly, even with highest levels of ASiR-V, no degradation of image quality is observed. This may be explained, at least in part, by the fact, that in the present study, CCTA was acquired with lower tube current and voltage than in previous studies. Thus, higher levels of IR may be more adequate to compensate increased noise at these radiation doses, allowing CCTA with ultralow-dose radiation exposure and with preserved image quality.

Furthermore, vendor specific characteristics of detector geometry, scanner design, and system resolution may contribute to differential performance of IR methods in various studies. The results of the present study may be at variance with those obtained with other IR algorithms on other scanners. The present study reports on the impact of latest generation IR on latest generation CT technology from one vendor. Therefore, extrapolation to application of ASiR-V and ASiR on other types of CT scanners—even from the same vendor—should only be done with caution.

We acknowledge the following limitation to our study. We cannot comment on the impact on diagnostic accuracy, due to the lack of a standard of reference. However, this was beyond the scope of the present study which aimed at evaluating the impact of different levels of ASiR-V on quantitative and qualitative image assessment. Furthermore, the protocol for contrast material volume and flow rates in our institution falls in the lower end of the range reported in the literature and recommendations. We

did not evaluate the potential impact of higher volumes and flow rates on the present results because we have focused on the impact of ASiR-V levels while keeping other parameters constant to avoid confounders.<sup>19</sup>

## CONCLUSIONS

Reconstruction with ASiR-V yields substantial image noise reduction and improved image quality for CCTA data sets acquired at low tube voltage and current, thus enabling robust introduction of ultralow-dose CCTA protocols.

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